Research Paper | E-ISSN NO : 2455-295X | VOLUME : 9 | ISSUE : 3 | SPECIAL ISSUE MARCH-2023

WIDE AREA MONITORING USING OPTIMIZED PHASOR MEASUREMENT UNITS

NARENDRA KUMAR	RESEARCH SCHOLAR, DEPARTMENT OF ELECTRICAL ENGINEERING M.B.M. UNIVERSITY, JODHPUR, 342001
SANTOSH KUMARI MEENA	ASSISTANT PROFESSOR, DEPARTMENT OF ELECTRICAL ENGINEERING M.B.M. UNIVERSITY, JODHPUR, 342001

ABSTRACT:

The A power system is a complex dynamic system made up of interconnected power equipment. It mainly consists of generation, transmission, and distribution units. In the current modern era where almost everything has been modernized for a more efficient, better reliability, and independent monitoring, traditional power grids are also in the transitional process to become a modernized power grid, or widely known as the smart grid. The vision for the smart grid is to monitor and manage the power grid as efficiently as possible while providing better reliability and stability. A phasor measurement unit (PMU) sends time-synchronized data to a phasor data concentrator (PDC), which can provide a control signal to substation devices. Phasor Measurement Unit (PMU) based Wide Area Measurement System (WAMS) can measure power system phasors synchronously and accurately. With the advent of wide-area measurement systems (WAMS), real-time calculations on transmission network condition is possible. One of the advanced technologies used is phasor measurement unit (PMU). PMU is a measurement device that can measure bus voltage phasor at the bus it is installed and the branch current phasor that is adjacent to it, hence, the name. PMU is also equipped with Global Positioning System (GPS), thus, the measurement data provided by the PMU can be calculated real-time due to time-stamping and synchronization. It aligns with smart grid visions to have a better monitoring of the power grid and more reliable. . Furthermore, the cost of the PMU itself is readily expensive although the price is expected to be decreased when there are more demands in future placement of PMUs in a power system.

KEYWORDS:

PHASOR MEASUREMENT UNIT (PMU), GLOBAL POSITIONING SYSTEM (GPS), WIDE AREA MONITORING SYSTEMS (WAMS)

1. INTRODUCTION

A power system is a complex dynamic system made up of interconnected power equipment. It mainly consists of generation, transmission, and distribution units. Generation and load are often located far apart and are interconnected through a transmission network maintaining the power demand and supply at equilibrium. An electric power system is therefore a network of electrical components designed to supply reliable, reasonably priced, and quality energy to consumers. The generation equipment generates electrical energy from other forms of energy, such as coal, hydro, nuclear, or fossil fuel, which are interconnected through networks of transmission lines (power grid). The transmission equipment transmits the bulk of the generated energy from one location to another at higher voltage levels. The distribution network finally distributes the energy to consumers at lower voltage levels. electrical grids are being operated closer to their stability limits because of ever expanding power demands, aging infrastructure, complex power transfers among regions, and challenging renewable integration. All these trends present an important challenge to the reliability and stability of the electrical grid and under such complexities, carrying out monitoring, protection on real time basis and responding to contingencies are critical for maintaining reliability and stability of the grid. SCADA/EMS systems were widely used as situational awareness technology however they provide only the steady state view of dynamically changing power system. Wide area measurement systems (WAMS) have come forward as a prominent technology option to improve the visibility and situational awareness in both today's and the future electrical grids. Synchrophasor technology is at the heart of WAMS system that has enabled state measurement in WAMS compared to state estimation in conventional SCADA systems. WAMS measurements are more accurate and faster compared to their SCADA counterparts. The faster and more accurate synchrophasor measurements enable accurate and faster analysis of current grid situation almost in real time which in turn provides operators with options to carry out preventive measures and time to act through early prediction of dangerous events. WAMS thus addresses not only the immediate reliability concerns but also operational issues by conducting real-time dynamic analysis, identifying and calculating security margins and indices, facilitating early detection and monitoring of system security, predicting emergency states and initiating restorative actions to avoid instability. In the current modern era where almost everything has been modernized for a more efficient, better reliability, and independent monitoring, traditional power grids are also in the transitional process to become a modernized power grid, or widely known as the smart grid. The vision for the smart grid is to monitor and manage the power grid as efficiently as possible while providing better reliability and stability. It is a welcome consideration to replace an ageing infrastructure with a smart grid that uses advanced technologies to achieve this vision. One of the advanced technologies used is phasor measurement unit (PMU). PMU is a measurement device that can measure bus voltage phasor at the bus it is installed and the branch current phasor that is adjacent to it, hence, the name. PMU is also equipped with Global Positioning System (GPS), thus, the measurement data provided by the PMU can be calculated real-time due to time-stamping and synchronization. This knowledge is vital to electric utilities especially to operator engineers where it allows them to identify, anticipate, and correct problems in case when irregular system conditions occur. It aligns with smart grid visions to have a better monitoring of the power grid and more reliable. However, the implementation of PMU has been progressing very slowly due to substantial investment needed for the placement sites. The PMU placement sites need to have a communication facility for the PMU to operate and the limited number of placement sites that have it hinders its implementation. Furthermore, the cost of the PMU itself is readily expensive although the price is expected to be decreased when there are more demands in future. Research conducted in recent years have shown that by utilizing the PMU attributes and the use of the Kirchoff’s current law (KCL) and Ohm’s law, the number of PMUs required to achieve full observability of a power system can be reduced if the PMUs are strategically placed in a power system. Many optimization methods have been used in recent years to determine the strategic placement of PMUs in a power system such as integer linear programming (ILP), simulated annealing (SA), exhaustive search (ES), genetic algorithm (GA), differential evolution (DE), and also binary particle swarm optimization (BPSO). Among these optimization methods, the ILP is the most dominant method used in solving this problem.

With the advent of wide-area measurement systems (WAMS), real-time calculations on transmission network condition is possible. A phasor measurement unit (PMU) sends time-synchronized data to a phasor data concentrator (PDC), which can provide a control signal to substation devices. Phasor Measurement Unit (PMU) based Wide Area Measurement System (WAMS) can measure power system phasors synchronously and accurately. The main advantage of PMU over conventional SCADA measurement system is that PMU can accurately measure phase angles of power system phasors while conventional instruments cannot measure phase angles directly. Secure operation of power systems requires close monitoring of the system operating conditions. The measurements received from numerous substations are used in control centers to provide an estimate for all metered and un-metered electrical quantities and network parameters of the power system, detect and filter out measurement and topology errors. Until recently, the available measurements were provided by SCADA, including active and reactive power flows and injections and bus voltage magnitudes. The utilization of global positioning system (GPS), in addition to sampled data processing techniques, for computer relaying applications, has led to the development of PMUs. Phasor measurement units are monitoring devices that provide extremely accurate positive sequence time tagged measurements. A PMU installed at a bus can make direct synchronized measurements of the voltage phasor of the installed bus and the current phasors of some or all the branches incident to the bus, assuming that the PMU has sufficient number of channels. With the increasing use of PMUs in recent years, improved monitoring, protection, and control of power networks can be achieved. The intended PMU applications, the relatively high cost of PMUs, as well as the communication facilities cost, which may be higher than that of the PMUs, make the optimal PMU placement problem an important challenge.

1.1 WIDE AREA MONITORING SYSTEMS

Wide Area Monitoring Systems (WAMS) are essentially based on data acquisition technology of phasor measurements, in order to monitor the transmission system conditions over large areas, in view of detecting and further counteracting grid instabilities. Today, a WAMS may be utilized as a stand-alone infrastructure that set off the traditional SCADA system. WAMS thus addresses not only the immediate reliability concerns but also operational issues by conducting real-time dynamic analysis, identifying and calculating security margins and indices, facilitating early detection and monitoring of system security, predicting emergency states and initiating restorative actions to avoid instability. It is also useful in post-mortem analysis of disturbances in power grid

The WAMS consists following major equipment.

- Phasor Measurement Units
- Fast communication channels like Fiber-Optic.
- Phasor data concentrator (PDC).
- Global positioning system (GPS)

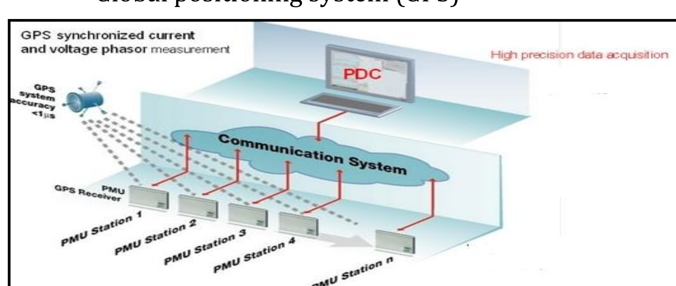

FIGURE: 1 WIDE AREA MONITORING SYSTEMS ARCHITECTURE

Figure 1 shows the typical architecture of wide area measurement system. WAMS has sensors, communication (wired and wireless), aggregators, storage and associated software tools. The Phasor Measurement Unit (PMU) acts as the sensor in WAMS and is synchronized using a global positioning system (GPS) clock to provide time-synchronized voltage and current phasors, as well as frequency measurements with synchronization accuracy better than microseconds.

PMUs are capable of collecting the samples at the rate of 10 to 60 samples per second. Synchronized measurements (data) obtained from the PMUs are sent through communication networks which are then received and concentrated at a decision and control support system called as Phasor Data Concentrators (PDC).

The PDC determines appropriate preventive, corrective and protective measures. The decisions determined by the support system will then help operators at control centers to take smarter operator control actions. These actions are translated into feedback signals that are sent through communication networks to exploit the controllability and protection resources of the power system. PMU and PDC are thus backbones of any WAMS system. The synchrophasor (angle and magnitude) technology at the heart of WAMS system has enabled state measurement in WAMS as against the state estimation in SCADA systems. The faster and more accurate synchrophasor measurements enable accurate and faster analysis of grid situation almost in real time which in turn provides operators with options to carry out preventive measures and time to act through early prediction of dangerous events.

The PMUs are located at a different substation and give measurements of positive sequence time synchronized current, voltage, the rate of change of frequency, and frequency. Foremost, the measurement information is stacked away in local data storage equipment and then it is used from outside positions for analysis or diagnostic uses. The local memory space is without doubt limited, and the data storage for any event of the power system should be flagged for stable storage, hence it has prevented the overwriting problem at the local store.

Moreover, once the data are measured, it is used for the real-time applications at the local level and the next level PDC also. The PDCs are located at the next level of the hierarchy.

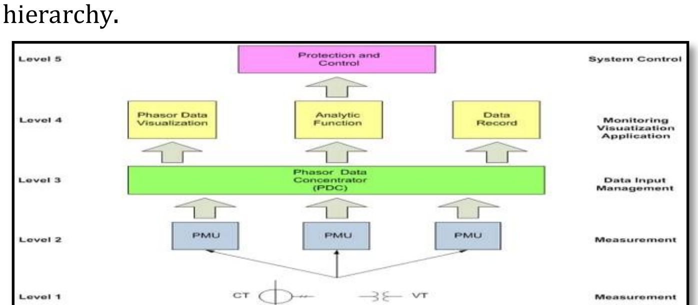

FIGURE: 2 WIDE AREAS MONITORING SYSTEMS COMPONENTS

1.2 PHASOR MEASUREMENT UNIT (PMU)

PMU is a device which measure the real time voltage and current and voltage phasor of a network and state estimate the measurements to get all the required variables for controlling and monitoring purpose and frequency of a given node. Due to wide area of possible applications many PMUs have been installed. Today the rapidly evolving scenario of distribution grid where the increasing the presence of distribution generators asked for increasing measurement accuracy faster reporting rate and higher communication capabilities. PMU measure both the magnitude and the phasor of the waveform and give output which is used to find the unknown components used for controlling and monitoring purpose. PMU consists of three basic units can be given as:-

- i. Synchronization Unit with clock
- ii. Measurement Unit which measure voltage and current waveforms
- iii. Data Transmission Unit to transmit data

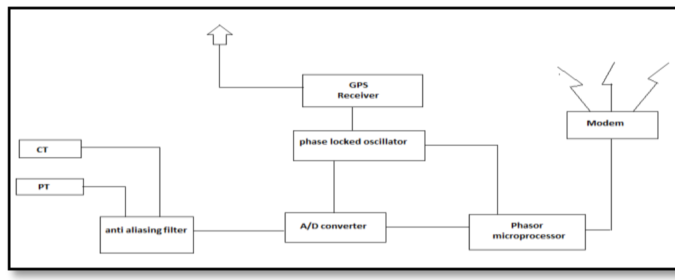

FIGURE 3: STRUCTURE OF PMU

1.3 OPTIMAL PMU PLACEMENT (OPP)

Phasor Measurement Units are capable of measuring the voltage and current phasor in real time. Also, PMU are able to measure the voltage and current phasor of the bus on which installed and the neighboring buses which are connected to PMU. This clearly shows that there is no need to install the PMUs at each bus in a power system network. By applying PMUs at selected locations only, all the buses can become observable. The complete Observability gives us the complex voltages at each and every bus of the power system. Once the information about complex voltages and network parameters are known then any electrical quantity of the power system network can be found very easily. In large and complex system, optimization technique help us for determining the minimal set of PMUs so that every bus of the power system network is observed by the minimal set of PMUs at least one time. placement of PMUs in a power system such as integer linear programming (ILP), simulated annealing (SA), exhaustive search (ES), genetic algorithm (GA), differential evolution (DE), and also binary particle swarm optimization (BPSO). Among these optimization methods, the ILP is the most dominant method used in solving this problem.

4. CONCLUSION

On Wide-area protection, currently, is a highly demanding research area. A comprehensive survey of present status of wide area protection and control applications in power system is carried out in this paper. One of the major issues in the application of this relatively new technology is integration of WAMS based adaptive relaying schemes with conventional protection schemes comprising of fault detection, fault identification and fault location. for optimal placement of PMU is presented in this paper. The new iterative method makes the test systems topologically observable by placing a set of minimum PMUs. The three stage algorithm is simple, fast and easy to implement. The present method obtains optimal solution using simple network connectivity information. the method in obtaining the minimum number of PMUs required for complete observability of power systems and also its advantage of computational efficiency.

REFERENCES

1. Gopakumar P, Chandra G S, Reddy M J B, Mohanta D K. Optimal placement of PMUs for the smart grid implementation in Indian power grid — A case study. Frontiers in Energy, 7(3): 358–372, 2013.

2. Y. Shi, H. D. Tuan, T. Q. Duong, H. V. Poor, and A. V. Savkin, "PMU placement optimization for efficient state estimation in smart grid," *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 1, pp. 71–83, 2020.

3. A. Dubey, S. Chakrabarti, and V. Terzija, "SCADA and PMU measurement based methods for robust hybrid state estimation," *Electric Power Components and Systems*, vol. 47, no. 9-10, pp. 849–860, 2019.

4. H. Manoharan, S. Srikrishna, G. Sivarajan, and A. Manoharan, "Economical placement of PMUs considering observability and voltage stability using binary coded ant lion optimization," *International Transactions on Electrical Energy Systems*, vol. 28, no. 9, Article ID e2591, 2018.

5. T. Johnson and T. Moger, "A critical review of methods for optimal placement of phasor measurement units," *International Transactions on Electrical Energy Systems*, vol. 31, no. 3, p. 3, 2020.

6. N. M. Manousakis, G. N. Korres, and P. S. Georgilakis, "Taxonomy of PMU placement methodologies," *IEEE Transactions on Power Systems*, vol. 27, no. 2, pp. 1070–1077, 2012.

7. R. Babu and B. Bhattacharyya, "Strategic placements of PMUs for power network observability considering redundancy measurement," *Measurement*, vol. 134, pp. 606–623, 2019.

8. S. Kumar, B. Tyagi, V. Kumar, and S. Chohan, "Optimization of phasor measurement units placement under contingency using reliability of network components," *IEEE Transactions on Instrumentation and Measurement*, vol. 69, no. 12, pp. 9893–9906, 2020.

9. M. K. Arpanahi, H. H. Alhelou, and P. Siano, "A novel multiobjective OPP for power system small signal stability assessment considering WAMS uncertainties," *IEEE Transactions on Industrial Informatics*, vol. 16, no. 5, pp. 3039–3050, 2020

10. Z. Jin, P. Dattaray, P. Wall, J. Yu, and V. Terzija, "A screening rule-based iterative numerical method for observability analysis," *IEEE Transactions on Power Systems*, vol. 32, no. 6, pp. 4188–4198, 2017.

11. Phadke, A.G., Volskis, H., de Moraes, R.M., Bi, T., Nayak, R.N., Sehgal, Y.K., Sen, S., Sattinger, W., Martinez, E., Samuelsson, O. and Novosel, D., 2008. The wide world of wide-area measurement. *IEEE Power and Energy Magazine*, *6*(5), pp.52-65.

12. M. B. Mohammadi, R. A. Hooshmand, and F. H. Fesharaki, "A new approach for optimal placement of PMUs and their required communication infrastructure in order to minimize the cost of the WAMS," IEEE Trans. Smart Grid, vol. 7, no. 1, pp. 84–93, 201

13. A. Pal, A. K. S. Vullikanti, and S. S. Ravi, "A PMU Placement Scheme Considering Realistic Costs and Modern Trends in Relaying," IEEE Trans. Power Syst., vol. 32, no. 1, pp. 552–561, 2017.

14. S. Nikkhah, J. Aghaei, B. Safarinejadian, and M.-A. Norouzi "Contingency constrained phasor measurement units placemen with n − k redundancy criterion: a robust optimisation approach," IET Sci. Meas. Technol., vol. 12, no. 2, pp. 151–160, 2018.

15. K. Satish Kumar and M. Sydulu, "Optimal PMU placement techniques for the topological observability of a partial network of the southern grid of India", vol. 3, no. PART 1. IFAC, 2014.

16. C. Lu, Z. Wang, M. Ma, R. Shen, Y. Yu, and S. Member, "An Optimal PMU Placement With Reliable Zero Injection Observation," IEEE Access, vol. 6, pp. 54417–54426, 2018.

17. S. P. Singh, A. K. Thakur, and S. P. Singh, "PMU Placement for Maximum Observability of Power System under Different Contingencies," Energy Procedia, vol. 117, pp. 893–900, 2017.

18. Nadia H.A. Rahman, Ahmed F. Zobaa "Optimal PMU placement using topology transformation method in power systems" Journal of Advanced Research 7, 625–634, 2016.

19. Rahul Gore, Mallikarjun Kande "Analysis of Wide Area Monitoring System Architectures" IEEE, 978-1-4799-7800-7/15, 2015.